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ABSTRACT

The essentials of Piaget's theory and its application to teaching at the college level are described as part of the Learning and Evaluation Service workshcp, Teaching Students to Reascn, offered at Michigan State University. Objectives are to enable the teacher to: (1) diagnose and classify reasoning patterns of students; (2) evaluate current instructional materials and techniques in light of Piaget's theories; (3) redesign instruction to inccrporate Piagetian concepts in order to facilitate the type of reasoning appropriate for the course; and (4) use guidelines for designing tocls to evaluate reasoning skills. Examples are presented frcm various subject matters to enable the teacher to understand how many of the principles can be applied to college courses. After close examination cf concrete and formal operation, a list of characteristics associated with each level of reasoning are presented, as are examples of student responses that can be classified accordingly. Some general teaching strategies that are useful to promote reasoning abilities in learning are presented for the fcllowing areas: when introducing a new topic, during instruction, when using the laboratory, when making assignments, and when testing. (SW)

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Teaching Students to Reason:
An Application of Piagetian Psychology to College Teaching

Kiavash Azima
and
Rebecca Henry

Paper #76

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Preface

This paper was written for use in the Learning and Evaluation Service workshop, Teaching Students to Reason. Portions of this paper have been taken from "Workshop on Physics Teaching and the Development of Reasoning," developed by the American Association of Physics Teachers; Accent on Developing Abstract Processes of Thought (ADAPT), University of Nebraska; and Science Teaching and the Development of Reasoning, University of California, Berkeley. These materials were edited by the authors for use in this paper.

Introduction

Have you ever wondered about the large differences in student reasoning ability at the college level? Most likely you have had some students who seem to be quite deficient in their use of reasoning. For example, many students are capable of solving simple problems in which numbers can be plugged into a formula or a recipe can be followed to obtain "the" solution. However, these same students can have a great deal of difficulty in employing appropriate strategies such as separating variables, excluding irrelevant factors, or applying certain mathematical relationships when they are needed in concert to solve a problem.

By ignoring these discrepancies among students, instructors may actually be teaching to only those students who are already operating at a high level of reasoning; while those learners who need additional assistance are not being adequately served in the course. The consequence of this can be differences among students which grow large over time.

The theories of Swiss psychologist Jean Piaget may be used to describe the development of reasoning skills in humans. His theories provide a basis for classifying student reasoning patterns. These classifications are based on what Piaget calls stages of intellectual development. Further, Piaget deals with the origin and the development of knowledge. Thus his theories may be used as guidelines for designing appropriate learning environments in which reasoning is promoted and in which effective learning takes place.

Purpose

This paper describes the essentials of Piaget's theory and its application to teaching at the college level. Specifically, this paper will: (a) provide you with ways and means that can be used to diagnose and classify reasoning patterns of your students; (b) enable you to evaluate your current instructional materials and techniques in light of Piaget's theories; (c) enable you to redesign your instruction to incorporate Piagetian concepts in order to facilitate the type of reasoning appropriate for the course; and (d) provide you with guidelines for designing tools to evaluate reasoning skills.

In applying Piagetian ideas to practical educational settings we will go beyond a strict interpretation of his theories. Rather than presenting a rigorous and comprehensive treatment of either Piaget or other psychologists in the field of problem solving and reasoning, we will provide practical criteria and checklists which may be used in any educational setting. We will present several examples from various subject matters to help you understand how many of the principles can be applied to college courses.

Overview of Piaget's Theory

Though Piaget began his career as a biologist, his efforts in the past fifty years have been directed toward formulating an elaborate theory of intellectual development which has provided a powerful framework for educators in understanding the acquisition of complex reasoning ability in students. Piaget's extensive work in biology influenced his position on psychological development in that he viewed intellectual growth as an extension of biological adaptation to the environment. Simply stated, Piaget's primary thesis is that intellectual development is a complex process of successive qualitative changes in mental structures; each structure and its subsequent change deriving from the preceeding one. In other words, new knowledge does not replace old knowledge, it incorporates it.

Piaget has identified four broad stages of cognitive growth which are critical for understanding the developing intellect; only the last two will be of direct interest in this paper. The concept of a stage theory is important to mention here as there are two key assumptions inherent in this view of development. First, the stages are invariant, that is the sequence of development is identical for all humans. In order to reach complex levels of reasoning all individuals must proceed through prerequisite stages. Only the rate of development differs among individuals. Secondly, development is cumulative, the quality of later intellectual behavior is dependent upon the quality of experiences which preceed it.

The developmental periods identified by Piaget are roughly described as:

1. Sensory-motor: behavior is primarily motor and the child is most responsive to physical interactions
2. Pre-operation: behavior is characterized by development of language and conceptual thinking

These stages are completed by age 7-8 and will not be considered for our purposes.

3. Concrete operation: the individual develops the ability to apply logical thought to concrete problems.
4. Formal operation: the individual is able to apply logic to all classes of problems and can employ hypothetic deductive reasoning.

In the next section a more detailed explanation of these two stages will be provided.

For Piaget, the motivating force behind all learning is a process called equilibration. Equilibration is the means by which an individual attains greater intellectual "balance" at successively higher levels of learning as new information is incorporated with the old. The person reaches new levels through one of two processes: assimilation or accommodation. When available information is integrated into existing intellectual structures, assimilation occurs. On the other hand when available mental structures cannot handle the information and existing ones must be modified, this is termed accommodation. The internal system is refined to fit the environment. Mental structures may be visualized as mental "blueprints" that guide an individual's behavior and his interactions with the environment. If these interactions are successful, his mental structures continue to guide his behavior. However, as an individual interacts with and manipulates his environment he may encounter phenomena that do not fit his present mental structures. This causes mental "disequilibrium." States of disequilibrium are by definition motivating in that they force the developing individual to construct progressively more complex structures in order to adapt to the demands of the external world. These more complex structures lead to more complex behaviors and further states of disequilibrium and so on. In other words, when an individual's present level of intelligence proves inadequate, when faced with new disequilibrating environments, intelligence must grow and develop in an equilibrated way in order to cope with the new and more complex environments.

Newly formed mental structures are relatively unstable. Repeated practice in application of the new ideas accompanied by appropriate feedback will serve to strengthen and stabilize these mental structures.

By the time adulthood is reached, most individuals are capable of creating their own internal disequilibria by imagining hypothetical situations and problems which stimulate productive thinking. For example, the person who thinks "What if...." and then proceeds on to solve his own problem in the absence of any external demands is providing his own disequilibrium.

In the next section we will be examining more closely what concrete and formal operations are all about. With each category, we will present a list of characteristics associated with that level of reasoning as well as examples of student responses which can be classified accordingly. As you are going through these sections, imagine students in your own class and attempt to classify their reasoning abilities.

Concrete Operations

The distinguishing feature of concrete operations is that objectivity and logic are employed in reasoning. Deductive thinking is applied to problems though the beginning point is always a real event and not a hypothetical situation.

The following is a guideline which can assist the instructor in classifying the thought patterns of students. While each item cannot be used as absolute evidence of the concrete stage, when employed as a set of clues the instructor should be able to make a useful and accurate identification.

Concrete Thought

Clues to Identify the Stage of Concrete Thought

Affirmative answers to:

(c1) Does the individual make simple classifications and generalizations (e.g., all dogs are animals, only some animals are dogs)?

(c2) Does the individual apply conservation logic (e.g., if nothing is added or removed, the amount remains the same even though the appearance may differ)?

(c3) Does the individual arrange a set of objects or data in serial order and establish one-to-one correspondence between two sets (e.g., given a set of floating objects, the one lowest in density will float the highest).

In these respects the individual can reason and solve problems beyond his ability in previous stages. Here are a few examples to illustrate these accomplishments. The individual now:

(ca) Understands concepts and simple theories that make direct reference to familiar actions and examples, and can be explained in terms of simple associations, ordering, or numerical equivalencies/differences (e.g., objects that do something to each other are in interaction - the waves are high because there is a strong wind);

(cb) Follows step-by-step instructions as in a recipe, providing each step is correctly specified;

(cc) Relates his/her viewpoint to that of another in a simple situation (e.g., a girl is aware that she is her sister's sister), and is able to take the position of another individual (e.g., imagine you are the mayor of a small city, how would you cope with the problems...)

Yet the advances in reasoning are limited as compared to those achieved at the stage of formal thought. The limitations may be detected as the concrete thinking individual now:

(cd) Searches for and identifies variables influencing a phenomenon, but does so unsystematically (e.g., investigates the effects of one variable but does not necessarily hold the others constant);

(ce) Relates observations and makes inferences from them, but does not consider all possibilities;

(cf) Responds to difficult problems by applying a related but not necessarily correct algorithm; a student indiscriminately applies a general algorithm to a special case which requires a modified algorithm.

(cg) Processes information but is not explicitly aware of his own reasoning (i.e., does not check his/her own conclusions against the given data or other experience).

Formal Operations

While students in the concrete operations stage are oriented toward real phenomena in the present sense, formal operating students are not bounded by concrete events. They are capable of performing logical operations on hypothetical events using abstract symbols. The student is able to combine multiple rules and operations to solve complex new problems and will formulate, execute and assess his own symbolic plans of action. Subsequently with these higher-order skills the student can engage in scientific reasoning, and hypothesis generation and testing.

Again, clues are provided as a guideline for classifying the reasoning patterns of formal operations.

Formal Thought

Clues to Identify the Stage of Formal Thought

Affirmative Answers to:

(f1) Does the individual reason with propositions regardless of whether they are factual or hypothesized?

(f2) Does the individual consider all conceivable combinations of experimental or theoretical conditions, even though some may not be realizable in nature?

(f3) Does the individual recognize and interpret functional relationships in situations described by observable or abstract variables (e.g., field strength is inversely proportional to the square of the distance, the volume of a cube varies directly as the third power of the edge length)?

(f4) Is the individual aware and critical of his/her own reasoning (e.g., recognizes options in using various models or approximations, or tests a conclusion to see whether it is based on a fallacious step)?

Here are a few further examples to illustrate these achievements.

The individual now:

(fa) Engages in hypothetico-deductive reasoning (performs logical operations on hypothetical events);

(fb) Plans experiments according to an overall design that investigates the effects of one variable while holding the others constant and also allows for unforeseen contingencies;

(fc) Uses theories and idealized models to interpret observations and draw conclusions;

(fd) Understands concepts defined in terms of other concepts or in terms of abstract relationships (e.g., ratios, mathematical limits);

(fe) Solves problems by introducing intermediate variables not given or asked for directly in the original statement.

In this next section, you will be given a set of examples* that represent concrete and formal thinking by students. As you read through them try to isolate those behaviors and reasoning patterns that refer either to concrete or formal thinking.

Example 1 - The Pendulum Problem

The pendulum problem consists of presenting the student with a pendulum in the form of an object suspended from a line. The line can be adjusted for length and a set of objects of varying weight can be substituted for the one tied to the line. The student is given a demonstration of all the factors that can be varied: string length, object weight, height of release point and the force of the push given to the object. The problem for the students is to find the factors that determine the frequency of the oscillations.

> Hal - He compares 20 grams on a short string to 50 grams on a long string and concludes, "it goes faster with the little weight." Next he performs the same task but changes the weights (50 grams with a long string and 100 grams with a short one). He states, "when its short it goes faster and I found that the big weight goes faster."
>
> Teacher, "Does the weight have something to do with it?"
>
> Hal, "Yes" as he takes a long string with 100 grams and a short one with 20 grams. "Oh, I forgot to change the string." He shortens it with the new weight on it. "The weight and the length affect the speed of oscillation."

Explanation: Concrete operations. At this level Hal is able to separate out the factors which can be manipulated and he tests a variety of different combinations. By the time he begins testing he has already ruled out two factors: force of the push and the height (at which the object is dropped).

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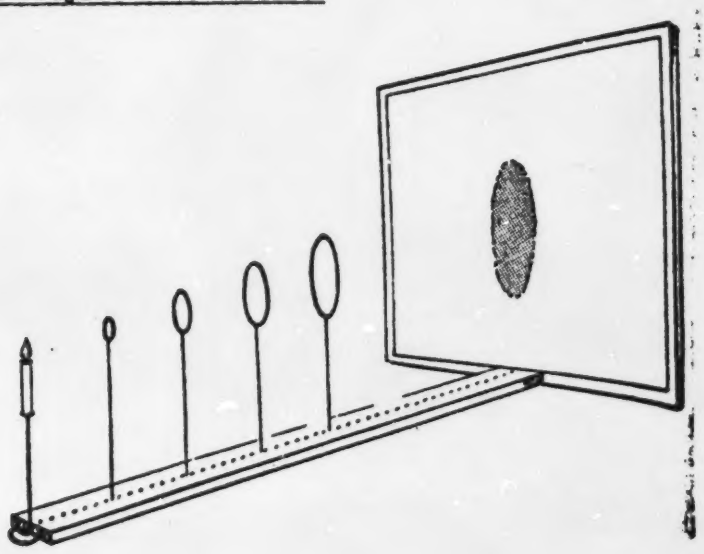
* The examples in this section are taken from The Growth of Logical Thinking by Piaget and Inhelder - France, Basic Books, Inc., 1958.

However, Hal is not systematically organizing his experiment. His major problem is that he always varies two factors simultaneously and,consequently, is unable to systematically exclude the irrelevant factors from his experiment.

> Anne - At first she believes all four factors could be influential. She studies different weights on the same string length and does not notice any change. "That doesn't change the rhythm." Next she varies the length of the string with a 200 gram weight and discovers, "when the string is short, the swing is faster." Finally, she changes the dropping point and the force with the same medium length string and 200 gram weight. She concludes, "Nothing has varied."

Explanation: Formal Operations. From the beginning, Anne's experiment appears to be deliberately planned to account for all available variables. She starts with the variables that she believes will have the greatest potential for influencing oscillation, though she is careful to test all the variables before finishing. Finally, Anne understands the notion of holding all variables constant except one to allow for exclusion of irrelevant factors.

Example 2 - The Projection of Shadows



The projection of shadows involves a base board, a screen, a light source and four rings of varying diameters. The light source and the rings can be moved along the baseboard. The student is asked to find two shadows that cover each other identically by using two unequal rings.

Allan - He reasons "Since the diameters all have regular differences, the differences between the distances have to be the same." Then he places the rings of 5, 10, 15 and 20 cm at distances of 8, 16, 24, and 32 cm. respectively; next he takes another arbitrary distance and finds the proportion in the same way. "The distances have to have the same relation to each other as the rings."

Answer: Formal operations - Allan employs proportional reasoning. He identifies the correct ratio which relates the rings.

Sally - "You have to put the smallest ring in front, toward the light source because it keeps getting larger. Why? Because the smallest have to be further back to make the same size as the big ones: you have to put them at almost equal distances apart."

Answer: Concrete operations - The qualitative correspondence between shadow size and distance is clearly established. However, Sally has not constructed the true multiplicative proportion that Allan has

in his experiment. Further her demonstration is based solely on the problem at hand while Allan has constructed the law which generalizes to all related cases. Sally is satisfied with demonstrating a correct single instance of the problem while Allan evidences a greater understanding of proportionality.

Evaluating Your Current Instructional Procedures and Materials

Texts and other instructional materials, such as practice problems and test items, may be classified according to the type of reasoning they require of the learner. Lectures and presentations may also be classified in a similar fashion. A diagnosis of your current instructional materials and lectures is important because it will help you redesign your course content to accommodate the concrete thinkers in your class. It will also help you identify those materials which may be used to challenge the formal thinkers.

In this section we will provide you with criteria for distinguishing between instruction which requires concrete thinking and instruction which requires formal reasoning skills. The next section (Design of Learning Activities which Promote Reasoning) will provide you with specific suggestions for possible modifications in the materials and procedures used in your course.

Criteria for Classifying Text Passages and Lecture Presentations

A text passage or a lecture requires only concrete reasoning if it:

1. Relates to learner's past experiences and to familiar objects, action, and examples (or relates to content covered earlier);
2. Uses an intuitive approach (e.g., instinctive reasoning);
3. Deals with real, not hypothetical phenomena;
4. Uses clearly defined terms;
5. Adequately demonstrates the points raised when possible, or otherwise provides an opportunity for the learner to "visualize" the phenomena rather than relying on abstract derivations (using graphs, diagrams, pictures, etc.);
6. Avoids complex relationships (those that go beyond a direct relation between two concepts);
7. Makes no logical "jumps;"
8. Material is presented from several different perspectives.

In contrast, test passages or lectures requiring formal reasoning skills are those which:

1. Rely on mathematical or otherwise highly symbolic reasoning;
2. Deal with hypothetical as well as real phenomena;
3. Deal with complex relationships;
4. Require the learner to fill in the missing steps in a hypothetic deductive argument or to make inferences or logical deductions.
5. Require the learner to recognize assumptions not explicitly stated.

Now, let us take a look at a few typical text passages to see how the checklists provided may be used in practice.

Excerpt -1

Sanford D. Gordon and Jess Witchel, An Introduction to the American Economy (D. C. Heath and Company, Boston, 1967).

Elasticity of demand

Not all demand curves look like the one shown in Figure 2-1. Let us look at the demand for salt rather than candy bars. The price of salt may vary from 10 cents a pound to 20 cents a pound. If your family uses between one and two pounds of salt a month, its expenditure for salt could fluctuate from 10 to 40 cents a month, depending on the extremes in the quantities used and the prices paid. Another way of looking at it is to say that the cost of satisfying your family's need for salt can fluctuate from ½ cent to 1⅓ cents per day, a 400 percent variation in price. There would probably be a very small decline in the sale of salt if the price increased 50 percent, or even 100 percent. The cost is so low, even at the highest price, that few people would deprive themselves. When a relatively large change in price brings about only a small change in the quantity purchased, we say that the demand for a product is *inelastic*. In other words, the demand for salt is inelastic. Another aspect to consider is what you could use in place of salt. A comparison of a curve plotted for candy bars and of one for salt would show a vast difference, the latter being far steeper.

(1)

If a seller has no competition and no fear of government's controlling the price, any increase he makes in the price of an inelastic product will increase his revenue from that product. What factors might restrain such a seller from using such power excessively? What considerations will determine where the price is eventually set?

(2)

An example of elastic demand

The demand curve for expensive meats is quite different from that for salt. When sirloin steak goes on sale, reduced from $1.35 a pound to $1 a pound, purchases are likely to increase by a far greater percentage than the percentage of the reduction in the price. Many shoppers who know that their families like steak seldom buy it because the high price would mean they would have to sacrifice too many other wants. However, a drop in price changes the whole situation. Fewer wants will have to be given up in order to obtain the satisfaction that steak provides. We can conclude that the demand for steak, being very responsive to a change in price, is elastic.

(3)

When a relatively small change in price brings about a large change in the quantity bought, we have a product with *elastic* demand. Think of elastic as stretching. A change in price that brings about little stretching (change) in the quantity bought is inelastic; a lot of stretching of quantity bought is elastic. Compare the curve of an elastic demand with that of an inelastic demand. Is it more important to have vigorous competition when a product is elastic or when it is inelastic?

(4)

A word of caution is in order before you try to analyze the elasticity of a product. In the case of most products the elasticity changes over a very broad price range. Steak may be quite elastic when its price fluctuates between 60 cents and $1.50. As the price goes above $1.50, it becomes less and less elastic. There will be a relatively small change in the quantity of steak sold when the price goes above $2. The relatively few who can afford to pay such a high price, or the few who feel they must have steak because of their dietary habits or the high want-satisfaction from eating steak, will probably pay the additional money no matter what the price.

Factors determining elasticity

What makes the demand for a product inelastic? Usually the demand is inelastic when (1) it is difficult to find a substitute, (2) it represents a small portion of an individual's budget, and (3) it is considered a necessity. Any one or a combination of these reasons will tend to make demand inelastic. Conversely, products for which there are many substitutes, which represent a large portion of the budget, and which are considered luxuries tend to be elastic in demand.

(5)

Most products will not fit neatly into either category, and what may have an elastic demand in one family may have an inelastic demand in another. Evaluate the elasticity of the demand for milk, a television set, your favorite magazine, a second car in a suburban family, and a first car for a low-income family in a metropolitan center.

Comments:

The first paragraph (1) may be classified as "concrete" - it uses ideas that relate directly to the learner's personal experiences (price of salt, family usage of salt, etc.); it deals with real everyday phenomena; it uses familiar terminology; and it avoids messy mathematical definitions.

The third and fourth paragraphs (3) and (4) also use familiar examples and relate to learner's experiences (e.g., "stretching"). These paragraphs may als be classified as concrete.

The second paragraph (2), however, does require the learner to make a few inferences and logical deductions.
For example, the idea of "revenue" is introduced, but not adequately defined and the learner must infer its relationship to "elasticity," "government," and "competion." To answer the two questions in this paragraph, the learner must determine the relevant variables and develop a model to explain the relationships involved. This paragraph requires a great deal of formal reasoning.

Excerpt -2

The sensitivity of purchases to price changes: Demand elasticity

Richard S. Eckaus, Basic Economics (Little, Brown and Company, Boston, 1972)

The theory of consumer choice provides the rationale for the general conclusion that the quantity demanded of any particular commodity will increase when the price is decreased. For each commodity, the sensitivity of its purchases to changes in prices will depend on all the factors that influence its demand. These may well result in different degrees of sensitivity at different price and income levels. (1)

The concept of *demand price elasticity* was invented to provide a measure of the sensitivity of purchases to price changes. It is tempting to use the *slope* or slant of the demand schedule as drawn on a graph for this purpose. But that is unsatisfactory, because the slope of the demand schedule depends on the particular units used to measure the quantities. Suppose, for example, that a household's demand curve for butter measured in pounds and in quarter pounds were that in Tables 20-5 and 20-6 and in Figures 20-5 and 20-6. With quantity measured in quarter pounds or with a larger space for each pound on the horizontal axis, the demand schedule in Figure 20-6 is made to look flatter and much more sensitive to price changes than the demand schedule of Figure 20-5. Yet it is the same demand schedule. Thus, the slope is a misleading indicator of demand elasticity. This problem is avoided by defining demand elasticity as a measure of the sensitivity of the response of quantity demanded to price changes in terms of *relative changes* both in prices and quantities. (2)

A numerical measure of the price elasticity of demand is computed in the following way:

$$\text{The price elasticity of demand, } e = \frac{\text{the percentage change in the quantity purchased}}{\text{the percentage change in price which caused it}}$$

Prices and quantities move in opposite directions, so this number, e, always has a minus sign if one is precise about it. Since elasticity is a little cumbersome to deal with when the minus sign tags along, we shall always refer to the *absolute value* of the elasticity, that is, the value without the minus sign. Even so, a problem arises in implementing this measure. The problem, which comes up in the calculation of relative changes, is, *Percentage change from what?* It is sometimes convenient to think of prices changing over time while everything else remains constant. Then there is a "first" and a "second" price and quantity. In the theory of consumer choice, however, the various prices and quantities are regarded as *alternatives*, with no specific "first" or "second." What does one do then? There are no perfect answers when we deal with real situations, but it is reasonable to split the difference when the differences are substantial. That is, when prices change from $9 to $11, the percentage change is *not* computed as ($9 − $11)/$9 or ($9 − $11)/$11, but as ($9 − $11)/$10. The demand elasticity using this convention is, therefore, computed by the equation:

$$e = -\frac{Q_2 - Q_1}{\frac{Q_2 + Q_1}{2}} \Big/ \frac{P_2 - P_1}{\frac{P_2 + P_1}{2}}$$

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When the quantity demanded is quite sensitive to price changes, then the percentage change in quantity will be greater than the percentage change in price which caused it, and the elasticity of demand will be greater than one. When quantity demanded is relatively insensitive to price changes, the percentage change in quantity will be less than the percentage change in price which caused it, and the elasticity of demand will be less than one. Right between them is the knife edge case of unitary elasticity in which price changes cause quantities to change in the same proportion as price. The range of elasticities can be represented as shown in Figure 20-7 for the absolute values of demand elasticity.

Comments:

The first paragraph (1) in this passage may be classified as one requiring formal reasoning. It introduces the concept of "sensitivity" with no concrete reference to familiar ideas or experiences. Reference is made to "all the factors that influence its demand" but these factors are not identified; they must be infered.

The second paragraph (2) "defines" elasticity in terms of what it <u>is not</u> and does so using the concept of slope which may or may not be familiar to the learner. This paragraph may also be classified as requiring formal thought.

This entire passage involves explanations of the economic concept of elasticity using abstract ideas from mathematics. It has something to do with "relative change," "absolute values," "percentage changes," a computation without reference to a familiar phenomena or a previously defined problem, and other concepts not adequately (concretely) defined or explained.

We would thus classify this passage as one requiring formal reasoning skills.

In the following section, we will provide you with criteria for classifying homework problems and test questions and some examples.

Criteria for Classifying Homework Problems and Test Items

We can classify a problem as "concrete" if the problem has the following characteristics:

1. A single formula can be used to solve it;

2. The variables in the problem can be observed directly (no "hidden" variables);

3. Calculations and procedures used to obtain solutions are simple requiring no
   (a) proportional reasoning;
   (b) graphical interpretation of abstract variables;
   (c) choosing among models or theories;
   (d) hypothesis formation and testing;
   (e) inventing models to explain a phenomena;
   (f) breaking problem into subproblems;
   (g) ability to invoke "relevant" analogies to problem situation;
   (h) hypothetico-deductive reasoning;
   (i) ability to discriminate between relevant and irrelevant variables; etc.

4. All necessary data is given.

A problem is "formal" it if has the following characteristics:

1. More than one formula must be used to solve the problem (combinations must be formed, new ones must be derived, etc.);

2. There are "hidden" variables, new variables must be introduced to facilitate solution, etc.;

3. Those reasoning abilities listed as <u>not</u> required for low level problems are <u>required</u> for high level ones;

4. A decision must be made re: which theory or approximation thereof is appropriate to the conditions of the problem;

5. Further data (not given) must be obtained either from problem situation or from other systems;

6. An overall plan (problem solving procedure) is needed before an equation or a formula can be used to obtain a solution;

7. Cases where <u>no solution</u> exists cannot easily be recognized.

Using the criteria described in the two preceding sections, identify whether the following problems are concrete or formal and then compare your answers with ours.

Problem 1

Four types of rats were bred for laboratory experiments. Type A rats were found to be more resistant to disease than Type C rats. Type B rats were less resistant to disease than Type C rats and Type D rats were more disease resistant than A rats. Which type of rats were least disease resistant? Explain your choice.

Answer

This item is classified as concrete. It requires the student to serial order a set of observations and deal with familiar concepts such as disease.

Problem 2

A geologists finds a sandstone bed 1000 feet in thickness. He notes the size of the sand particles, and by studying the patterns of deposition, determines that the sandstone bed was deposited by stream action. He finds a stream which is carrying particles of the same size and which is depositing the particles in the same patterns. This stream deposits 1 foot of sand every ten years on the average. The geologist concludes that the sandstone bed was deposited over a period of at least 10,000 years. Which of the assumptions below, which the geologist made, is probably valid?

a. Streams carried particles in the past as they do today.
b. Particles being deposited today are similar to particles deposited in the past.
c. The deposition of the sandstone bed was continuous and constant.
d. Gravity and climate acted on streams in the past as they do today.
e. Three of the above are probably valid.

Please explain your choice.

Answer

This item is considered formal in that it requires the student to recognize hidden assumptions and understand the geologists' current application of an invalid assumption.

Problem 3

Use the following demand schedule to determine total and marginal revenues for each possible level of sales.

Produce Price	Quantity Demanded	Total Revenue	Marginal Revenue
$2	1	_____	_____
$2	2	_____	_____
$2	3	_____	_____
$2	4	_____	_____

Answer

This problem can be solved by direct application of simple definitions of total and marginal revenue. A concrete thinker who has memorized the terminology should be able to do that, even though he may not understand many of the ramifications and applications of the idea of marginal revenue which he will encounter later. We, therefore, call this problem a "concrete" problem.

Problem 4

New York City has had rent controls since 1941. What effect do you think this has had upon the demand for housing? Upon the construction of new housing?

Answer

This problem would probably leave the concrete thinker completely lost. Giving him only a single sentence of data, with no "clue" terminology to tell him where to search for an algorithm,it presents great difficulties. It demands he locate a relevant theoretical framework, determining relevant variables, and applying them correctly. Rent controls are nothing he has heard a formula about, and he has to be able to translate them into a supply-demand statement. Nearly impossible.

Design of Learning Activities Which Promote Reasoning

Piaget's theory of intellectual development outlined earlier suggests that for classroom instruction to be effective it must be sequenced so that:

> Instruction starts with a presentation of concrete (familiar) phenomena followed by an introduction of new (unfamiliar) phenomena causing cognitive disequilibrium. The instructor then assists the learner in formulating new explanations and theories and provides an opportunity for application of the new ideas and for appropriate feedback.

In this section we will explore one instructional application of the above mentioned principle called the Learning Cycle.

The Learning Cycle

Recently, Karplus* has suggested a Piagetian-based classroom instructional strategy that may assist students in their development of logical thought. This flexible strategy is called the Learning Cycle and provides some guidance for instructors who wish to combine the development of reasoning with the mastery of content.

The Learning Cycle is divided into three major phases known as Exploration, Invention, and Application (sometimes called Discovery). The general characteristics of each phase of the Learning Cycle are:

> Exploration - Following a brief statement of topic and direction, students are encouraged to learn through their own experience. Activities are supplied or suggested by the instructor which will help the students to recall (and share) past concrete experiences and to assimilate new concrete experiences helpful for later Invention and/or Application activities. During this activity the students receive only minimal guidance from their instructor and explore new ideas in a spontaneous fashion.
>
> Invention - In the invention phase the concrete experiences of the exploration are used as the basis for generalizing a

* Karplus, R. Science Curriculum Improvement Study, Teachers Handbook, University of California - Berkeley, California, 1974.

concept or for introducing a principle. Student and instructor roles in this activity may vary depending upon the nature of the concent. Generally, students are asked to invent part or all of the relationship for themselves with the instructor supplying encouragement and guidance when needed. This procedure allows the students to gain confidence through familiarity with the concepts introduced.

Application - The application phase allows each student an opportunity to directly apply the concept or skill learned during the invention activity. Application provides the students with additional broadening experiences. They use the invented concepts in different concrete settings.

The Learning Cycle allows each student the opportunity to think for himself. The instructor is a present overseer of activity. Yet he must guard against over playing his role as director and facilitator. He must provide an open classroom atmosphere within a well-defined boundary.

The Learning Cycle offers you a model for designing instructional activities which may encourage your students to develop their reasoning skills and to learn concepts. In the following portions of this paper we offer some details of the Learning Cycle, its applications, and our guidelines for using the Learning Cycle to design classroom activities. The outline below describes the three parts of the Learning Cycle in detail.

A. Exploration

Emphasis - Concrete experience with familiar objects and systems

Focus - Open-ended student activity.

Function - Student experience is joined with appropriate environmental options not previously considered by the student.

1. This phase of the Learning Cycle provides students with reinforcement of previous concrete experience and/or introduces them to new concrete experiences related to the invention objectives.
2. Exploration allows for open-ended consideration, encouraging students to use concrete experiences to consider new ideas.
3. During Exploration the instructor supplies encouragement, provides hints, asks questions, and suggests alternatives. The instructor

should encourage students to try a variety of experiments.

4. Student behavior during Exploration provides information concerning the students ability to deal with the concepts and/or skills being introduced. The students will reveal the reasoning skills which they evoke in search for the solution to a problem.

B. Invention

Emphasis - Generalization of concrete experiences and abstract possibilities.

Focus - Student's active involvement with instructor for generalization.

Function - Students become familiar with generalized concepts and/or skills.

1. During Invention students are encouraged to formulate relationships wh'ch generalize their new ideas and concrete experiences.
2. The instructor acts as a mediator in assisting students in formulating these relationships to be consistent with results of their exploration activities.

C. Application

Emphasis - Relevant use of generalized concepts and/or skills.

Focus - Directed student activity.

Function - Further use of generalized concepts in other systems.

1. To begin the Application, the students and the instructor may interact in planning an activity for applying the invented concept and/or skill. The activity should provide a new or unique concrete situation.
2. Students are asked to complete the designed activity to the satisfaction of the instructor. The activities should provide further experience which will act as broadening and stabilizing experiences related to the new skills or concepts.

Physics Learning Cycle Example - Periodic Motion

A. Instructional Objectives

1. Introduce students to the general properties of periodic motion and to a subset of systems which illustrate simple harmonic motion.
2. Provide appropriate symbols and names for the variables used in discussing simple harmonic motion.

3. Invent a mathematical relationship between mass, period, and amlitude for a system which vibrates in simple harmonic motion.

B. Exploration Activity

Students are provided with the following instructions:

Name_____

Lab Partner_____

PERIODIC MOTION

Exploration Activity

On various tables in the lab you will find systems which oscillate periodically when displaced from their rest (equilibrium) positions. The type of systems include the following:

A. Rolling motion (weighted by clinders)
B. Bobbing motion (long flexible rods)
C. Vibrating motion (mass vibrated by fixed hacksaw blades)
D. Swinging motion (cylinder hung on fixed support)

Please investigate the properties of as many of these types of periodic motion systems as time allows. As you observe them, look for and identify the following characteristics:

1. Physical variables which are present in each of the systems.
2. Physical variables which can be controlled (held constant) while other variables are allowed to change.

What experiments could you design to investigate the properties of the systems above? What data would you collect and what methods might you see for analysis?

Rationale: Many students involved in this activity have had experience with oscillating objects; fish bobbers, swings, pendulum clocks. Most, however, have not considered the properties of systems which illustrate simple harmonic motion. Concrete experience is expanded by providing familiar and unfamiliar systems for exploration. Students are encouraged to explore by changing variables within a single system. A cognitive challenge was provided by asking students to compare common controllable

variables found in each system. The exploration was designed to provide needed concrete experience for the Invention activity.

C. Invention Activity

When students finish their exploration they are given the Invention sheet below and encouraged to invent many of the concepts on their own.

NAME_____

PERIODIC MOTION

Invention Activity

1. List the characteristics of the various systems which were different.

2. List the characteristics of the various systems which were similar.

3. What experimental tools could be used to investigate the nature of the similar characteristics of the systems listed in 2 above? What does the experimenter do about the other variables of the system?

4. What mathematical and/or graphical tools could be utilized in investigating the relationships between period, restoring force, amplitude, mass and/or length for each of the systems that vibrate. How would you set up an experiment for collecting the data needed?

Rationale: In beginning the invention, the instructor requires that students discuss the results of their exploration. This interaction provides a check on student progress and indicates a readiness to begin the invention phase.

The invention activity allows for instructor leadership in assigning common symbols and names to variables the students explored. Then depending on students ability, the relationships between force, displacement, mass and period can be introduced. Before completing the Invention, the instructor should provide an example showing how each of these variables influence one of the systems investigated during the exploration activity.

D. Application Activity

NAME_____

LAB PARTNER_____

PERIODIC MOTION

Application Activity

Your lab instructor will provide you with apparatus for another oscillating system, the rubber band-mass system.

Equipment: 1 rubber band
1 meter stick
1 set of metric masses
1 support rod
1 timer

Carefully design and perform an experiment which will provide the following information about this system:

A. Force (measured in grams) needed to stretch the rubber band through some given distance. (Are there any limitations to this measurement?)
B. Force constant of the rubber band in grams/cm. Is this constant always constant? (Hint: Plot a graph showing displacement (x) vs. grams of load (y) and take the slope of the graph.) Is the graph linear?
C. Period of oscillation as a function of the mass of the oscillating object.

Rationale: The application activity requires the students to directly apply the Invented relationships between amplitude, mass, displacement, and period. The activity may center upon one of the examples used for Exploration but is more effective if it uses a new setup such as the rubber band oscillation shown above. This activity serves to broaden

students learning by providing a system where they can directly apply the invented concepts.

Summary

So far in this section we have been talking about characteristics of instruction that promotes reasoning abilities in learners. Now we would like to present in summary form a list of strategies that many college professors have found effective. These general teaching strategies are as follows:

A. When Introducing a New Topic

1. Use EXPLORATION activities at the beginning of a new topic or before introducing a new concept.
2. Use concrete concepts defined operationally through demonstration, examples, and actions to introduce a new topic. At a later time, present more formal definitions of the same concepts and other ones.
3. Challenge your students to raise questions or predict the outcome of experiments. Don't squelch a timid first attempt. Then use the actual results to start an examination of unexpressed assumptions or expectations.

B. During Instruction

1. Allow your students time and opportunities for abundant and repeated experiences. The amount of material covered in your course, at least during the early weeks, may have to decrease.
2. Require students to present their ideas or answers in more than one form. They might use a formula, a graph or numerical result and a diagram. Alternative ways of perceiving relationships help students to resolve contradictions and become aware of their own reasoning. You might then ask them to justify their conclusions, predictions, and inferences regardless of whether these are correct or incorrect.

   Questions you might ask a group or an individual are:

   Why are you sure of that?
   What is the evidence?
   How could you explain that to me?
   What other ways of thinking about that problem are there?

3. Encourage your students to interact with one another during discussions and problem-solving sessions.
   Students using formal reasoning patterns will serve as role models for those using primarily concrete patterns. The latter, because of their more limited understanding, will challenge their advanced classmates' short-cuts in reasoning, thus making them rethink their ideas.
4. Model the reasoning behavior you hope to foster. Reason out loud when you present an explanation or answer a student's question. Let students know that you consider alternative possibilities and are at times unsure of how to proceed. Propose hypotheses, make inferences, compare them with other data, and examine evidence.
   Invite the class to join you in this activity by commenting on your ideas, proposing others, and evaluating suggestions. Leave some questions unanswered--they may be too difficult or the answer may be completely unknown.
5. Avoid the following behaviors, which tend to make your students' thinking remain at a superficial level:
   a) allowing so little time for responses to a question that few students have time to think about their answers;
   b) evaluating the first answer and then taking control of the discussion without waiting for comments from other students;
   c) suggesting all or part of an answer to your own questions rather than inviting students to propose even partial solutions;
   d) requiring your students primarily to recall pieces of information as opposed to relating or evaluating information.

C. <u>When Using the Laboratory</u>

1. Always begin with twenty to thirty minutes (or more) of EXPLORATION allowing the students to use their equipment with only a very general goal. Be patient, even if at first they make discoveries that do not fit your plans for the outcome of the session.
   After EXPLORATION, be clear and explicit when introducing the new idea or relationship that is at the focus of the day's lab. Encourage your students to help you formulate the new concepts

by drawing on their experiences during EXPLORATION.

2. In preparation for a lab activity, invite your students first to identify the variables that might affect the phenomenon to be studied. Then give them a written list of their own suggestions and encourage them to design experiments for testing these. By referring to their own list of variables, your students may learn to control variables more effectively.
3. Raise questions with your students that lead them to reflect on their activities and interpretations. Examples are:

   What were your steps in setting up this experiment?

   How would you proceed if you wanted to get better data when repeating the experiment?

   What parts of your report would you like to revise?

   What conditions in your experiment contributed most to the uncertainity of your measurements?

D. When Making Assignments

1. Before making an assignment from your text, identify the demands for formal reasoning it presents; perhaps supplement it with short explanations that will help students using concrete reasoning patterns. Note the clarity of the illustrations and whether they help communicate the message of the text.
2. Assign specifically constructed problems that allow students to evaluate their own reasoning, such as:
   (a) comparing a general case with simpler limiting cases,
   (b) using two methods for finding a result and comparing,
   (c) analyzing an incomplete problem statement for missing information and solving after making one or more supplementary hypotheses,
   (d) making a qualitative estimate of the result or using dimensional reasoning before calculating it exactly, and then comparing.

   The questions should not be tricky and should enable the student to get immediate feedback about the success of his procedure. Comparing with the "correct" answer always helps, but may not provide insight into the source of errors. Unfortunately, few textbook questions have these qualities, but are either very

difficult or encourage direct application of a memorized definition or formula.

E. When Testing

1. When you select items for a test, make sure that their demands on science knowledge and on reasoning are appropriate. Avoid problems in which ingenious reasoning overshadows the science--use these only in supplementary materials for gifted students.
2. Include test items on which you ask students to justify their answers so you can assess their reasoning patterns as well as their knowledge.

Concluding Remarks

In this paper we have suggested one approach to the analysis of human reasoning ability, namely that of Piaget's stages of development. We have also suggested ways to analyze and classify instructional materials to determine whether they are suitable for students at the concrete level of reasoning. This is important because recent research (e.g., Renner and Lawson, 1973) has shown that approximately half of the college students are at the concrete level of reasoning. Thus instructional materials and techniques must be developed to accommodate those with reasoning deficiencies.

At the same time, we feel that instruction at the college level ought to be made challenging and rewarding for the formal thinkers. Instruction must be designed to promote reasoning abilities in both concrete and formal thinkers. Characteristics of such a learning environment were presented in the previous section. While there may be other ways to achieve the same outcomes in students, we feel that the Learning Cycle approach presented here provides a flexible framework which makes this strategy adaptable to many instructional settings.

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